Spin Filter with Polarized Superfluid: Effects of Surface and Interface

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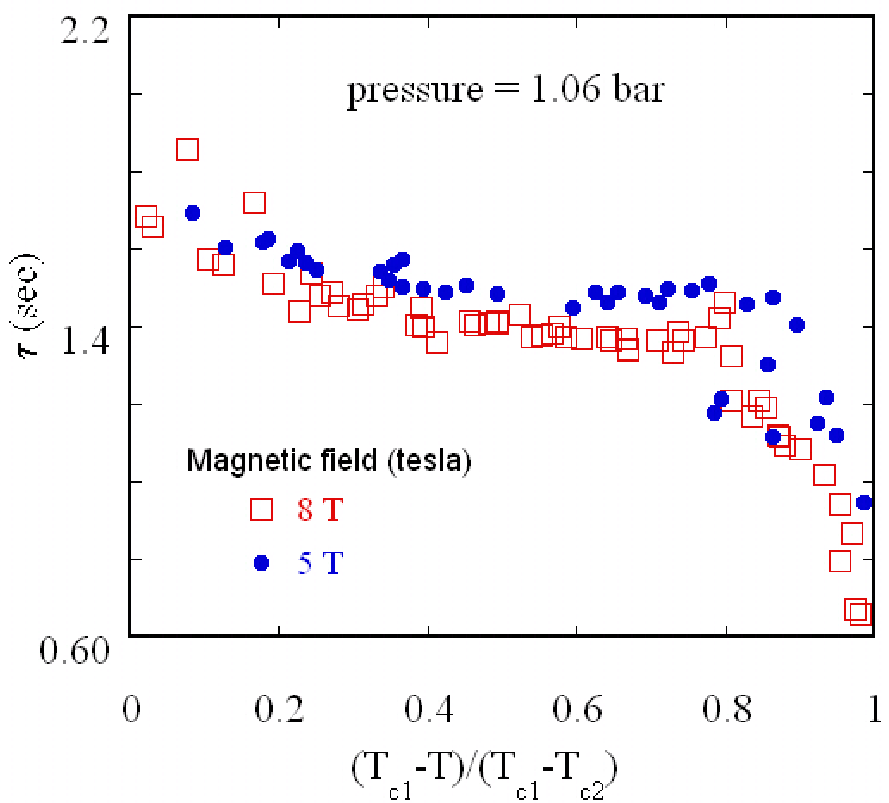
The spin fluid dynamics of the spin-aligned superfluid ^3He A1 phase is investigated. A novel magnetic fountain pressure effect detector is used to probe the nature of spin transport and relaxation effects. The magnetic fountain pressure is induced by applying a magnetic field gradient across a superleak connecting two chambers. The relaxation time of the induced fountain pressure has been measured as functions of temperature, pressure and magnetic field. The relaxation time is, *unexpectedly*, independent of magnetic field and temperature except near T_{c2}. Understanding our observations requires a new theoretical model for the spin relaxation.



Understanding the effects of magnetic fields on materials is extremely important in the development of new technologies that affect almost every aspect of modern life. The technologies such as electric light, motors, computers, superconducting magnets, magnetic resonance imaging (MRI) resulted from fundamental research on materials properties in magnetic fields. This research funded by NSF is one such research and aims to study the effects of magnetic field on the liquid helium-3 in its superfluid state at ultra cold temperatures. The ultra cold helium-3 (the "sister" isotope of helium-4 used in balloons) provides unusual properties unavailable in any other material to study the coexistence of superfluidity (flow without friction) and ferromagnetism (as in magnetism of iron).

Although the magnetism in helium-3 is relatively weak, a strong magnetic field has very strong influence on the helium-3 superfluid flow properties. When the superfluid helium-3 is placed in a large magnetic field, it transforms spontaneously into a totally new magnetic superfluid, so-called, A1 phase. The remarkable property of the A1 phase is that it carries a truly 100 % polarized magnetization (or equivalently, quantum mechanical spin) exactly along the applied magnetic field direction. It is this extraordinary property of A1 phase that gives exciting opportunities for research.

By applying gradients in magnetic field, the 100 % polarized magnetized superfluid can be manipulated to flow from one region to another in an apparatus. The fluid flow induces extra pressure which can be measured. The most remarkable aspect of our research is that the flow and dynamics of the magnetic material can be measured by simple mechanical pressure sensors to study the dynamics of the spin motion.

Our studies on the spin motion are important in understanding and development of the emerging spintronics technology. In spintronics devices, the spin of electron is utilized in addition to the conventional electrical charge to transfer information. The spin transport and dynamics of spin-polarized electrons is similar to our spin-polarized flows in helium-3. Understanding of spin dynamics in helium-3 can be then be applied to analyze spin dynamics in spintronics devices. Our experiments have advantages in simpler structures, ease of altering material conditions, and longer time scale involved.

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Broader Impacts

An active area of research is on the use of electron spin (in addition to its charge) for application in devices, or spintronics. Crucial to realization of spintronics devices is the understanding of motion and relaxation of inhomogeneous electron spin distribution. The transport and dynamics of spin-polarized electrons is akin to our spin-polarized flows in ^{3}He A_1. The nature of spin transport and diffusion can be explored more conveniently in our experiments. By changing the magnetic properties in the spin filter (superleak), their effects on the spin polarization relaxation may be studied. Our studies on the spin transport across different types of interfacial boundaries can be carried out in apparatus simply by changing temperature. Such modifications with semiconductor interfaces are difficult. Our studies of spin dynamics has much to contribute to understanding of spintronics.

Education and Outreach

The graduate student, K. Kimura, the postdoctoral fellow and R. Masutomi participated in the research. The Research Associate A. Yamaguchi and Professor H. Ishimoto at the Institute for Solid State Physics (ISSP) of the University of Tokyo are collaborating with us on the project. The experiments in very high magnetic fields and ultra low temperatures are carried out at the modern state of the art facilities at ISSP in Kashiwa, Japan. The research on our superfluid ^{3}He was highlighted at the annual open house at Rutgers University. Posters were displayed and laboratory tours were conducted. After the annual Irons Lecture Series of Rutgers Physics Department, a tour of our ultra low temperature laboratory was given to the public. A similar public outreach event took place at ISSP.

Research is also supported in part by a Research grant from Japan Society of Promotion of Science(JSPS).

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